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Atomic and Molecular Absorption at High Redshift

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Abstract. Strong constraints on possible variations in fundamental constants can be derived from H I 21-cm and molecular rotational absorption lines observed towards quasars. With the aim of forming a statistical sample of constraints we have begun a program of systematic searches for such absorption systems. Here we describe molecular rotational searches in 25 damped Lyman-α systems where, in many cases, we set optical depth limits an order of magnitude better than that required to detect the 4 known redshifted millimeter-wave absorbers. We also discuss the contributory factors in the detectability of H I 21-cm absorption, focusing on possible biases (e.g. low covering factors) in the currently known sample of absorbers and non-detections.

1. Introduction

Quasar absorption lines are powerful probes of possible variations in fundamental constants over cosmological distances and timescales. Recent studies of the relative positions of metal-ion atomic resonance transitions in optical (Keck/HIRES) quasar spectra are consistent with a smaller fine structure constant in the intervening absorption clouds over the redshift range $0.2 < z_{\rm abs} < 3.7$ (Webb et al. 1999, Murphy et al. 2003). This surprising and stubborn result can be cross-checked via several independent means, either using further optical data from a *different telescope/instrument* or possibly from other quasar absorption line techniques. Two such techniques are the comparison of H I 21-cm absorption lines with corresponding metal-ion optical transitions (Cowie & Songaila 1995) and the comparison of H I 21-cm and molecular rotational (i.e. millimeter-band) absorption lines (Drinkwater et al. 1998, Carilli et al. 2000, Murphy et al. 2001). However, the paucity of systems exhibiting H I 21-cm and optical/mm-band absorption severely limits this endeavor. Here we describe our recent attempts to improve this situation.

2. Search Strategy and Results

2.1. Source selection

Recently we have commenced a program of scanning the frequency space towards optically dim millimeter-loud systems in search of possible absorbers responsible for the visual obscuration (see Murphy, Curran, & Webb 2003). Prior to this, we selected DLAs as targets for our search since these are the highest column density ($N_{\rm HI} \gtrsim 10^{20}$ cm^{-2}) QSO absorbers known. Also, since there are many known DLAs with very precisely measured absorption redshifts, they present the opportunity to form a statistical sample of absorbers. Additionally, 7 of the 10 known H_2-bearing DLAs have high molecular fractions [$f(H_2) \sim 10^{-2} - 10^{-4}$] (see Reimers et al. 2003), so detection of tracer molecules such as CO and HCO^+ may be possible.

To undertake a systematic search for new high redshift H I 21-cm and molecular absorbers we produced a catalogue of DLAs (Curran et al. 2002b)[1] and shortlisted those which are illuminated by radio-loud quasars (i.e. those with a measured radio flux density > 0.1 Jy). This yielded around 60 DLAs occulting quasars of sufficient centimetre flux. Of these, 37 have been searched for 21-cm absorption (see Kanekar & Chengalur 2003, Curran et al. 2003). Selecting those of sufficient 12 mm and 3 mm flux gives 18 DLAs which have previously been searched for absorption (see Curran et al. 2003). Our recent GBT[2] and BIMA[3] observations have increased this number to 30 (Curran et al. 2004b).

2.2. Redshifted 21-cm results

Using the Parkes radio telescope, in January 2002 we searched for 21-cm absorption towards 3 high column density ($N_{\rm HI} \geq 4 \times 10^{20}$ cm^{-2}) DLAs (0432–440, 0438–436 & 1228–113) strongly illuminated ($S \geq 0.35$ Jy) by the background quasar at ≈ 400 MHz (the frequency of the line at $z \sim 2.3$). Unfortunately, due to severe interference in the 70-cm band, we have still to fully reduce this data. We note, however, from the published literature (e.g. Kanekar & Chengalur 2003) that only half of the 34 DLAs previously searched have been detected in 21-cm absorption, despite high neutral hydrogen column densities and strong quasar illumination. In the literature, the lack of a detection is usually attributed to a high spin temperature of the neutral atomic gas, based on no other information than the column density of the Lyman-α line.

After satisfying ourselves that the non-detected DLAs have been searched sufficiently deeply, we have several reservations about invoking high spin temperatures, the main being the lack of information on the covering factor of the quasar (usually assumed/estimated to be unity). Although little is known of the extent of the 21-cm absorbing region, through the sizes and morphologies of the background sources our preliminary results suggest that the quasar coverage

[1] A version of this catalogue is continually updated on-line and is available from http://www.phys.unsw.edu.au/~sjc/dla

[2] The Green Bank Telescope is operated by the National Radio Astronomy Observatory.

[3] The Berkeley Illinois Maryland Association array is operated with support from the National Science Foundation.

could indeed be a crucial factor in explaining the non-detections. Any conclusions about a redshift-dependent spin temperature, and therefore likely DLA host galaxy morphology (Kanekar & Chengular 2003), may suffer from a further observational bias: 21-cm absorption detections tend to occur in the $z_{\rm abs} < 1.8$ DLAs which were identified through the Mg II 2796/2803 Å doublet, whereas the non-detections at higher $z_{\rm abs}$ are mostly systems identified through the damped Lyman-α line. If low covering factor is even partially responsible for the high-z non-detections, the true range in spin temperatures may be far less than that currently estimated (20 to > 9000 K), though it may still be consistent with the hypothesis that $z > 2$ DLAs arise in compact galaxies (see Kanekar & Chengalur 2003, Lanfranchi & Friaça 2003, Curran et al. 2004a).

2.3. Redshifted millimeter results

We have now completed a deep survey of millimeter absorption lines in DLAs using the Onsala 20-m, Swedish-ESO Sub-millimetre Telescope (Curran et al. 2002a), the Australia Telescope Compact Array (Curran et al. 2003) and, most recently, the GBT and BIMA (Curran et al. 2004b). From this and the previously published work, 20 DLAs have been searched to 3σ limits of $\tau \lesssim 0.2$ (at 1 km s^{-1} resolution), i.e. an order of magnitude better than that required to detect the weakest known mm-absorber ($\tau \approx 0.7$ at $\lesssim 4$ km s^{-1}, Wiklind & Combes 1994). The best limits obtained thus far are $\tau < 0.06$ for CO $0 \rightarrow 1$ (Takahara et al. 1987) and $\tau < 0.03$ for HCO$^+$ $0 \rightarrow 1$ (Curran et al. 2004b). Using $N_{\rm H_2} \sim 10^4 N_{\rm CO}$ (Wiklind & Combes 1998) the former limit gives $N_{\rm H_2} \lesssim 1\% N_{\rm HI}$, which is the ratio of the strongest optical H_2 detection in a DLA and so may suggest that in some cases we are close to the CO detection limit. The HCO$^+$ limit may be a better choice since, unlike the CO molecule, a constant $N_{\rm HCO^+} = 2 - 3 \times 10^{-9} N_{\rm H_2}$ is found over various regimes in the Galaxy (Liszt & Lucas 2000). This gives the less impressive limit of $N_{\rm H_2} \lesssim N_{\rm HI}$ for the DLA in question. It should be emphasised, however, that converting these limits to molecular hydrogen column densities is somewhat difficult since Galactic conversion ratios are based upon dusty, high metallicity systems, which DLAs are not. We can however use the CO and HCO$^+$ limits to give column density ratios of $N_{\rm CO} \lesssim 10^{-7} N_{\rm HI}$ and $N_{\rm HCO^+} \lesssim 10^{-9} N_{\rm HI}$ per unit line-width (see Curran et al. 2002a). The former value is consistent with the values of $N_{\rm CO} \lesssim 10^{-8} N_{\rm HI}$ obtained from the $z > 1.8$ redshifted CO electronic transitions (Black et al. 1987, Ge et al. 1997, Lu et al. 1999, Petitjean et al. 2002).

3. Summary

We have performed deep radio and millimeter integrations of known high column density absorbers (DLAs) at high redshift in search of H I 21-cm and molecular absorption. From our results in conjunction with those previously published:

1. The 50% detection rate of 21-cm absorption may be due to selection and possible geometrical effects, rather than high gas temperatures. This would bring the estimated values of the spin temperatures at high redshift down closer to Galactic values while still permitting the absorbers to be compact galaxies.

2. We have searched for redshifted millimeter absorption to sensitivities an order of magnitude better than that required to detect absorption in the 4 known systems. The CO rotational limits for DLAs at low redhshift are consistent with those obtained from electronic transitions redshifted into the optical band at $z > 1.8$.

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